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Stability of GaInP/GaAs Tandem Cells under Concentration

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Stability of GaInP/GaAs tandem cells under concentration

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ABSTRACT

We present a study of the stability of GaInP/GaAs tandem cells under concentration, to enhance understanding of the long-term reliability issues that are important for the intended commercial terrestrial concentrator application.

1. Introduction

Although GaInP/GaAs tandem cells cells have been fully qualified and experience-tested for space operation at one sun, there does not appear to be any study in the literature of the stability of these cells under *concentration*. In studying stability, it is important to identify the degradation and failure mechanisms that are relevant to the conditions the device actually encounters in the field. While the likelihood is that field degradation of the cell under concentrator operation will be found to be linked to such real-world issues as poor bonding to the metallization, exposure to moisture, unintended reverse-biasing, etc., it is valuable to consider a simpler preliminary question: do these cells exhibit degradation when operated under concentration in an ideal laboratory environment? Here, we study the effect on GaInP/GaAs cell performance of concentrator operation under a solar simulator. GaInP/GaAs tandem cells were studied, as well as their individual components: GaAs and GaInP single-junction cells, and the tunnel-junction interconnects.

2. Tunnel Junctions

To study the tunnel junctions in isolation from the rest of the tandem device structure, a test structure was used which contains only the tunnel junction, allowing its IV curve to be measured, as shown in Fig. 1. After the baseline IV measurement, current was passed through the tunnel junction for an extended period of time by using a power supply to forward-bias the junction, simulating its operating state in a tandem cell (except the junction was not illuminated). The first “current soak”, for 27.5h at a current corresponding to concentrator operation at 700 suns, had no measurable effect on the IV curve. After the second current soak, at an elevated plate temperature of 50°C for 18.5h at an equivalent concentration of 280 suns, a very slight increase in the reverse-bias series resistance is seen, and an even smaller change in the forward-bias characteristic.

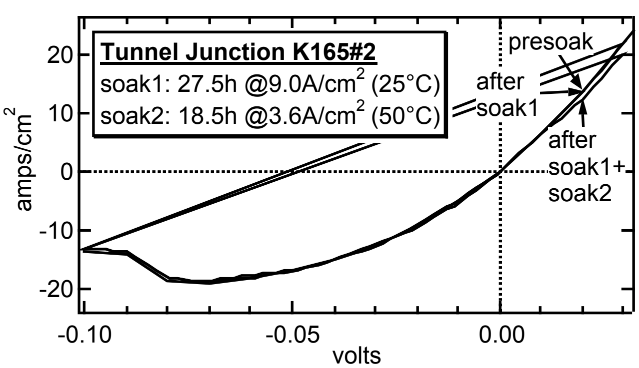

Fig. 1. Tunnel junction IV curve before and after extended operation under forward bias.

2. GaInP and GaAs cells

We next studied the stability of single-junction GaInP and GaAs cells. Neither cell had an antireflection (AR) coat. The cells were illuminated by xenon arc lamp light concentrated by Fresnel lenses to 100–250 suns. The cells were operated under this illumination at their maximum power points for periods on the order of fifty hours, at a receiver-plate temperature of ~25°C. After each such period the dark and light IV characteristics were measured for comparison with the pre-soak performance. First, a GaInP top cell was soaked at 110 suns for 43 hours. During illumination, the receiver-plate temperature was 22.5°C, and the cell was maintained at its maximum-power point. From a measurement of open-circuit voltage V_{OC} vs. time while the light was unshuttered, the junction temperature during illumination is estimated to be 34°C. After the soak, there was a noticeable increase in the dark current at low bias voltage, but, as shown in Fig. 2, not enough to cause any change in the light IV characteristic within the precision of that measurement. A similar light-soaking was done on a GaAs bottom cell for 66.5 hours at 250 suns. This cell also showed an increase in the dark current after light-soaking, but the increase was much less than for the GaInP cell. The light IV underwent negligible change upon light-soaking.

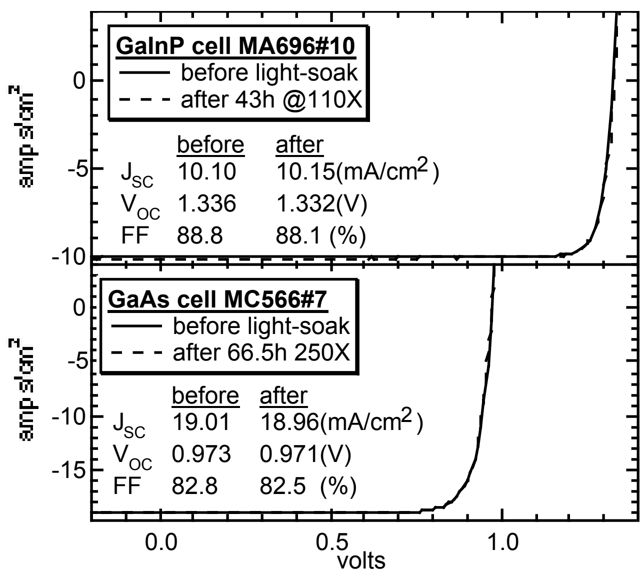

Fig. 2. GaInP and GaAs cell one-sun IV curves before and after light-soaking as described in the text.

3. GaInP/GaAs tandem cells

A similar approach was used to characterize the effect of concentrator operation on GaInP/GaAs tandem cells. Figure 3 shows the effect of 137 hours of 224-sun concentrator operation on the IV curve of a GaInP/GaAs tandem cell with a MgF_2/ZnS AR coat. There is enough of an increase in the dark current up to relatively high forward bias voltage that the V_{OC} of the cell is reduced by 29 mV, a non-negligible change. This cell was one of several fabricated on the same wafer. The dark currents for these other cells were also observed to increase after the concentrator soaking of device #7, even though the other devices were not illuminated. This suggests that the increase in the dark currents is due to heating of the wafer. The change in V_{OC} for each device on the wafer is shown in the inset in the lower panel of Fig. 3. The magnitude of the decrease in V_{OC} appears to be correlated with the distance of the device from device #7, the one which was illuminated, which would be consistent with a wafer-heating model of the V_{OC} degradation.

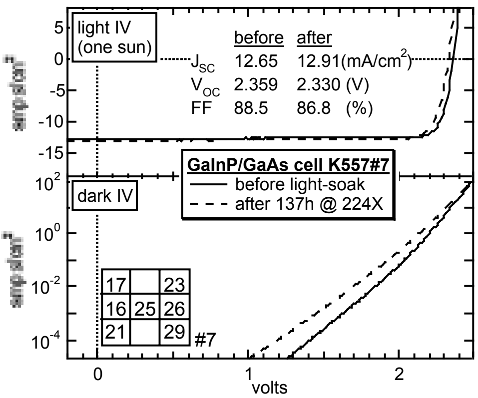

Fig. 3. Light and dark IV curves for a GaInP/GaAs tandem cell before and after operation at the maximum-power point at 224 suns illumination for 137 hours. The inset in the lower panel shows the decreases in V_{OC}, in mV, for each device on the wafer containing device #7, with the placement of the device on the wafer indicated by its position in the sketch.

4. Heat soaking

To study this, and to determine whether the degradation is related to the grid metallization, we processed pieces of a

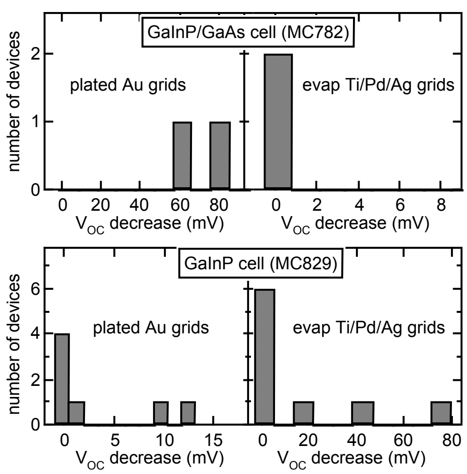

Fig. 4. Histograms of decrease of V_{OC} after 24 hour bake at 74°C for devices on two different wafers, processed with two different metallizations.

GaInP top cell and a GaInP/GaAs tandem cell with two different types of metallizations: evaporated Ag/Pd/Ti, and plated Au. For each piece of wafer and metallization type, several devices were put on the wafer. After making baseline IV measurements on the completed devices, we baked them in an oven for 24 hours at 74°C, and then remeasured the IVs. Again taking V_{OC} as a summary measure of the degradation, Fig. 4 shows histograms of the decrease in V_{OC} for the devices on each wafer piece. We see that the degradations are not uniform; rather, the devices degraded either significantly or not at all. This pattern is consistent with a catastrophic degradation mechanism rather than an incremental one. An attack on the top cell by the grid metallization would be an example of a possible catastrophic mechanism, although the comparison in Fig. 4 between the two different types of metallizations does not show an unambiguous distinction between the two.

Finally, we baked the devices again at 74°C for an additional 71 hours, and remeasured the IV curves on the devices which had not originally degraded. The histogram of V_{OC} decreases for these remaining devices is shown in Fig. 5 (all the devices of the four panels of Fig. 4 are combined here for brevity.) Of these remaining devices, two degraded significantly while the remainder show a very small V_{OC} loss of 3 mV on average. This distribution again points to a catastrophic degradation mechanism which is nonuniform across the wafer, suggesting that isolated defects in either the as-grown wafer or the metallization are responsible.

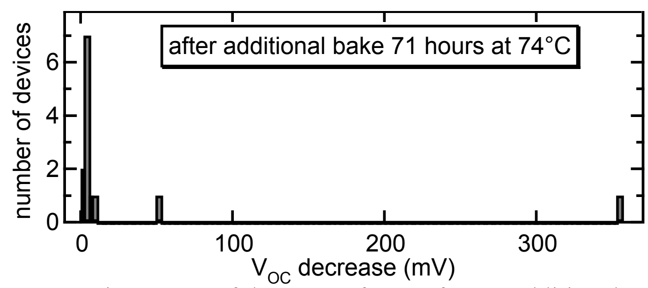

Fig. 5. Histograms of decrease of V_{OC} after an additional 71 hour bake at 74°C, for all the devices of Fig. 4 which had not already shown the catastropic degradation.

5. Discussion and Conclusion

It should be reemphasised that the pattern of degradation seen here may not be directly relevant to what one would observe in devices in the field. First, there are likely to be stresses present in field operation which we have not included in this study. Second, the devices we tested are not identical in growth, processing, and packaging to the commercial devices that would be put in commercial modules. For instance, since our devices were not encapsulated before the baking stress test, one might expect that they would be subject to a greater likelihood of oxidation-induced degradation than encapsulated device in a commercial module would be. Further study of concentrator cell stability will be an ongoing long-term effort, with the work described here serving as the prelude.